Final Report on

Large and Small Scales in Geomagnetic Field Modeling

NASA grant NAGW-3932

for the period 2/1/94-1/31/97

Principal Investigators:
Catherine Constable
Robert L. Parker

Institute for Geophysics and Planetary Physics,
Scripps Institution of Oceanography,
La Jolla, CA 92093-0225.

1. Final Report NAGW-3932

Under the funding provided by this grant we have carried out research in two major areas, global, regional and crustal field modeling of 20th cetury data, and studying the long term variation of the geomagnetic field observed through paleomagnetic data.

1:1 Regional and Crustal Modeling

We have developed a theory of regularized downward continuation and field modeling suitable for the study of crustal magnetization over large regions. The principle used is to apply the criterion of minimum complexity as embodied in an appropriate model norm or seminorm, but to restrict the model to a finite-dimensional subspace of fields spanned by a harmonic basis. The basis studied so far is the one associated with a distribution of point monopoles or dipoles, the same set often used in modeling the crust with the equivalent source technique. We have written computer programs implementing the theory and compared the results of our approach with those obtained in a number of studies that have used the classical equivalent source solution, or spherical cap analysis, whenever the data are available. The results of this work show that our monopole bases can be used effectively for modeling the geomagnetic field on all kinds of spatial scales (from regional to global), and are summarized in the paper by O'Brien & Parker (1994).

Two other papers on core-field modelling derived from work carried out under this grant (O'Brien, 1996; O'Brien *et al.*, 1997). The first by O'Brien (1996) deals with the issue of resolution of core field models, and shows that flux patches of a given sign at the core-mantle boundary are often poorly constrained. The present field can be adequately described by just two patches of opposite sign despite the fact that more typical field models contain 8 or more. This work highlights the flexibility possible in core-field models, which is due to uncertainties in the data arising from measurement errors and crustal and external field contributions. In O'Brien *et al.*(1997) it is shown that these uncertainties allow the construction of field models that are compatible with the frozen-flux approximation, under which secular variation is minimally influenced by diffusion. This paper also studies the structure of crustal field contributions for the 1915 historical dataset, and makes comparisons with predictions from theoretical models of crustal magnetization. The results demonstrate the need for better crustal field models at short and intermediate wavelengths- an issue we have begun to address under this grant using aeromagnetic profiles from Project Magnet and are continuing in Nasa grant NAG5-2968 (see O'Brien *et al.*,1996; Parker & O'Brien, 1996).

1:2 Long Term Field Modeling (0-5Ma)

We have completed our compilation of all the available paleosecular variation directional data from lava flows for the past 5 Ma to create a robust and reliable database on which a new generation of models of long term geomagnetic field behavior can be based. The details of the database are given in a paper by Johnson & Constable (1996) in Philosophical Transactions of the Royal Society of London. The database is also available by anonymous ftp.

We have used temporal averages from each geographic location represented in the database to provide data and uncertainty estimates that may be used to generate average field models for the time period 0-5 Ma. In doing this we have used the now rather standard techniques for finding regularized geomagnetic core field models. The special consideration here is that the data only provide directional information about the paleofield so the average field model reflects departures from the geocentric axial dipole field. More than 90% of the power in the paloefield can be accounted for by a geocentric axial dipole; however there are significant second order structures in the field. Several interesting results derive from the field modeling we have undertaken. Firstly, we find distinct differences between the statistical distributions of normal and reverse polarity paleomagnetic data. The cause of these differences remains unclear, but may reflect the fact that it takes more than one polarity epoch to obtain a representative average of the geomagnetic field. Because of these differences we have generated seperate normal and reverse polarity field models for the time periods 0-5Ma. These are known as LN1 and LR1. We have also modeled the current normal polarity Brunhes chron data independently of the rest (model LB1); it is the only single polarity interval for which we have sufficient data to do this. The results of our modeling clearly indicate that the data are not adequately fit by a zonal model for the geomagnetic field. Also the Brunhes chron cannot be distinguished from other normal polarity times on the basis of these observations.

Paleofield modelling has been extended to include a large marine sediment data collection. This has resulted in substantially improved spatial sampling and better constrained time-averaged field models, known as LSN1 and LSR1. The 0-5Ma field has small but significant non-zonal contributions, the largest of which appear to reflect anomalies in the time-averaged field beneath the central Pacific. These anomalies appear to reverse sign with the polarity of the field. The significance of these has been investigated further through comparisons with seismic models, as both global seismic tomography and regional studies suggest anomalous core-mantle boundary structure in this region. We conclude that the strcuture in our field models is likely to derive from lateral heterogeneity in thermal structure and compositional variations at or near the core-mantle boundary.

Work appearing in the following papers, thesis, and abstracts was supported under this grant:

Papers

Johnson, C.L., & C.G. Constable, 1995. The time-averaged geomagnetic field as recorded by lava flows over the last 5Ma. *Geophys. J. Int.*, **122**, 489–519.

Johnson, C.L., & C.G. Constable, 1996. Palaeosecular variation recorded by lava flows over the last 5Ma. *Phil. Trans. Roy. Soc. London*, **354**, 89–141.

Johnson, C.L., & C.G. Constable, 1997. The time-averaged geomagnetic field: global and regional biases for 0–5Ma. submitted to *Geophys. J. Int.*.

O'Brien, M.S., 1996. Resolving magnetic flux patches at the surface of the core. *Geophys. Res. Lett.*, **23**, 3071–3074.

O'Brien, M.S., & R.L. Parker, (1994). Regularized geomagnetic field modeling using monopoles. *Geophys. J. Int.*, **118**, 566–578.

O'Brien, M.S., Constable, C.G.,& Parker, R.L., (1997). Frozen flux models of the geomagnetic field for epochs 1980 and 1915. *Geophys. J. Int.*, in press.

Thesis

O'Brien, M.S., 1996. *Representation and Hypothesis Testing in Core and Crustal Geomagnetism.* PhD Thesis. University of California at San Diego

Abstracts

Constable, C.G. , 1994. The time-averaged geomagnetic field and paleosecular variation models: possible constraints from paleointensity observations. *EOS Transactions, American Geophysical Union*, **75(44)**, 193, presented at San Francisco Fall AGU Meeting.

Constable, C.G. , 1995. Paleointensity, the time-averaged geomagnetic field and paleosecular variation. *Annales Geophysicae, Supplement 1 to Volume*, **13**, C75, presented at European Geophysical Society Meeting, April 1995.

Johnson, C.L., & Constable, C.G., 1994. Observational constraints on long-term properties of the geomagnetic field. *Session*, **S4**, presented at SEDI meeting, Whistler, Canada, August 1994 .

Johnson, C.L. & Constable, C.G. , 1994. The time-averaged geomagnetic field over the last 5Myr. *EOS Transactions, American Geophysical Union*, **75(44)**, 194, presented at San Francisco Fall AGU Meeting.

Johnson, C.L., & Constable, C.G., 1996. Paleosecular Variation and Time Averaged Geomagnetic Fields: Global and Regional Biases for 0-5Ma. *EOS Transactions, American Geophysical Union*, **77(22)**, W142, presented at Brisbane, Western Pacific AGU Meeting.

O'Brien, M.S., Parker, R.L., & Constable, C.G. , 1994. Improving resolution in core-geomagnetic field models by

applying crustal field corrections to geomagnetic data. *EOS Transactions, American Geophysical Union*, **75(44)**, 197, presented at San Francisco Fall AGU Meeting.

O'Brien, M.S., Parker, R.L., & Constable, C.G. , 1995. Global Characterization of the Crustal Magnetic Field: New Uncertainty Estimates for Core Field Modelling. *EOS Transactions, American Geophysical Union*, **76(46)**, F174, presented at San Francisco Fall AGU Meeting.

O'Brien, M.S., Parker, R.L., & Constable, C.G. , 1996. A global magnetic power spectrum. *EOS Transactions, American Geophysical Union*, **77(46)**, F172, presented at San Francisco Fall AGU Meeting.

Parker, R.L., & O'Brien, M.S. , 1996. Spectral analysis of vector magnetic profiles. *EOS Transactions, American Geophysical Union*, **77(46)**, F172, presented at San Francisco Fall AGU Meeting.